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A NOTE ON THE USE OF (GRAY LEVEL, LOCAL AVERAGE GRAY LEVEL) SPA--ETC(U)
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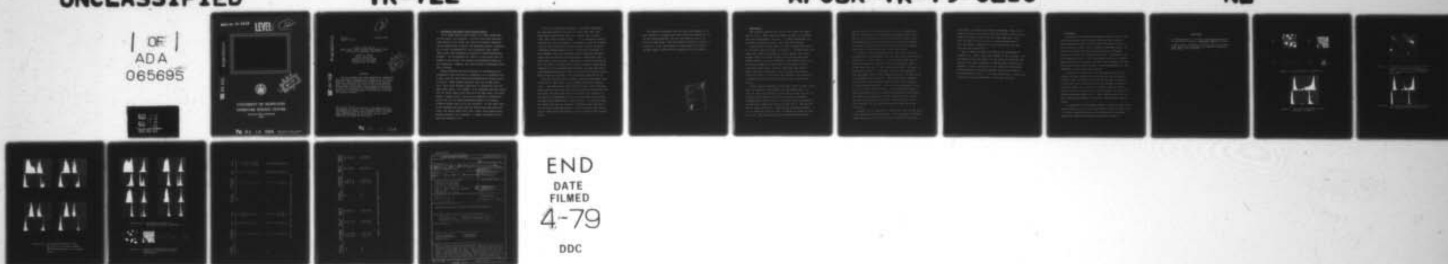

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A NOTE ON THE USE OF (GRAY LEVEL, LOCAL AVERAGE GRAY LEVEL) SPACE AS AN AID IN THRESHOLD SELECTION

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ABSTRACT

Various methods have been proposed for improving the gray level histogram of an image so as to make it easier to select thresholds for segmenting the image. This note describes how (gray level, local average gray level) feature space can be used to define improved image histograms. The approach is analogous to that in an earlier note which made use of second-order gray level histograms ("cooccurrence matrices") for similar purposes.

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1. Histogram improvement using feature spaces

If an image contains dark objects on a light background or vice versa, its histogram (a plot of how often each gray level occurs in the image) may contain two peaks, representing the populations of object and background points, separated by a valley corresponding to the intermediate gray levels (which occur less frequently, primarily on object/background borders). If we threshold the image at a gray level near the bottom of this valley, the objects and background should be well separated. However, the valley bottom is sometimes difficult to locate.

Several methods have been proposed for transforming the histogram so that the valley is deepened, or is converted into a peak, with the result that good thresholds may become easier to select. These methods generally make use of edge value (e.g., gray level gradient magnitude) in conjunction with the gray level itself. For example, if we histogram the gray levels only for those image points that have low edge value, we should obtain a deeper valley, since we are (hopefully) suppressing points that lie on object/background borders, and keeping primarily points that lie in the interiors. On the other hand, if we histogram the gray levels of points that have high edge value, the valley should turn into a peak, since these points should primarily lie on borders. A number of methods of this type are reviewed in [1].

In [2], an alternative approach to histogram improvement was described, based on the use of second order gray level histograms ("cooccurrence matrices") rather than on (gray level, edge value) scatter plots. In a cooccurrence matrix, elements near the main diagonal correspond to pairs of neighboring gray levels that do not differ greatly; thus if we define a modified histogram based only on points that contribute to such elements, then this histogram should primarily represent points that are interior to the objects or background, and so should have a deeper valley. Conversely, if we use only points that contribute to elements far from the diagonal, these should primarily lie on object/background borders, so that the resulting histogram should have a peak in place of the original valley. These ideas were verified in the experiments reported in [2].

This note presents still another alternative approach, based on the use of (gray level, local average gray level) scatter plots. The entries near the diagonal of such a plot represent image points at which the gray level and local average gray level are nearly the same; such points are likely to be interior to the objects or background, so that the histogram of gray levels of these points should have a deeper valley. On the other hand, the entries far from the diagonal represent points that should lie on object background borders, so that the gray level histogram of these points should have a peak in place of the original valley.

The modified histograms obtained using this method are no more expensive to compute than those using the approach in [2], and the results obtained (see the next section) seem to be better in some cases. Thus this method provides an alternative to those in [1-2], particularly in cases where the locally averaged image is already being computed for other purposes.

2. Experiments

The proposed approach was tested on the same four images used in [1-2]. These images are shown in Figure 1, and their gray level histograms in Figure 2. In these histograms, the left end corresponds to white, the right end to black.

Scatter plots of gray level vs. 3-by-3 average gray level for the four images are shown in Figure 3. In these plots, the upper left corner corresponds to (white, white); gray level becomes darker as we move downward, and average gray level becomes darker as we move rightward. Note that the plots are not exactly symmetric around their main diagonals (unlike cooccurrence matrices); points at which the gray level is darker than the average gray level are below the diagonal, while the reverse is true above the diagonal. The intensities on these plots have been log scaled for easier interpretability.

Figure 4 shows histograms of the gray levels of those points that lie exactly on the diagonal of each scatter plot. In part (a), the valley bottom is wiped out; in parts (b) and (d), a clear valley appears in place of a plateau or shoulder (respectively); but in part (c), the small peak (representing the writing) is wiped out along with the valley. The improvement in parts (b) and (d) is much better than that obtained in [2], while the parts (a) and (c) results are about the same as in [2]. The fact that the present method yields better results than [2] is not surprising, since in a cooccurrence matrix, even points on object/background borders will contribute to the near-diagonal region of the matrix (such a point has neighbors along the border whose gray levels are similar to its own), whereas such points will not have near-diagonal (gray level, local average gray level) value pairs.

Figures 5-8 show histograms of the gray levels of the p% of the points lying farthest above the diagonal of each scatter plot, for p = 5,2,1, and 1/2. In other words, these are the points for which the difference $\bar{f}-f$ was greatest, where f is the gray level and $\bar{f}$ the average gray level. For each p, we chose the highest t such that the points for which $\bar{f}-f \geq t$ were at least p% of the total number of points; all such points are included in the histogram. These histograms, especially for p=2,1,1/2, display single peaks that lie in the valleys of the original histograms. (For p=5, the histograms in parts (a) and (d) have become bimodal.) Thus the modes or means of these histograms provide reasonable thresholds for the images. The results are comparable to those obtained in [2], except that the peaks obtained in case (c) (the writing) are not as well centered, but are shifted toward the light end of the gray scale.

Figures 9-12 are analogous to Figures 5-8, but for the points lying farthest below the diagonals. Here the peaks are farther toward the dark end of the gray scale, and appear to be much less useful as a basis for choosing thresholds. This is because in all four cases there are fewer interior points in the dark regions than in the light ones (see especially (c-d), where the dark objects are thin or noisy (respectively)); thus the "border" populations of dark points are more like their interior populations.

Table 1 shows the means and modes of the histograms in Figures 5-12. Table 2 shows the average of the two means, and the average of the two modes, for the pairs of histograms that represent the same percentages of points above and below the diagonal. (This is analogous to [2], where the off-diagonal point populations used were symmetric around the diagonal of the cooccurrence matrix.) It is seen from Figure 13 that these averages yield good thresholds for all four pictures.

3. Discussion

An approach to histogram improvement based on (gray level, local average gray level) scatter plots has been presented. When we histogram only the points that contribute to the diagonal entries of such a plot, we obtain a deepened valley; the results are better than those obtained using an analogous approach [2] based on cooccurrence matrices. Conversely, when we histogram the up to 2% of points whose entries are farthest above and below the diagonal, we obtain two unimodal histograms; the average of the means or modes of these histograms is a good threshold in each of the cases tested.

It should be pointed out that the points giving rise to entries near the diagonal of the scatter plot are just those points at which the magnitude of the digital 3-by-3 Laplacian is near zero, while entries far from the diagonal correspond to points having very positive or negative Laplacian values. Thus the method presented here closely resembles the Laplacian-based approach described in [1]. Note, however, that here we have distinguished between the positive and negative Laplacian values.

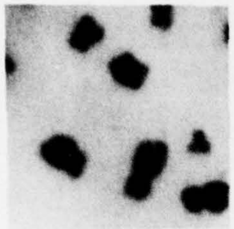
In conclusion, the approach defined in this note supplements those reported in [1-2], and yields better results in many cases. It is thus a useful addition to the repertoire of histogram improvement methods for threshold selection purposes.

References

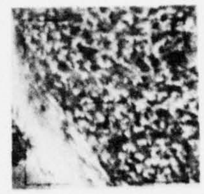
1. A. Rosenfeld and J. S. Weszka, Histogram modification for threshold selection, IEEE Trans. SMC-9, in press.

2. N. Ahuja and A. Rosenfeld, A note on the use of second-order gray level statistics for threshold selection, ibid. SMC-8, 1978, 895-898.

(a)



(b)



(c)

(d)

Figure 1. Pictures used in experiments

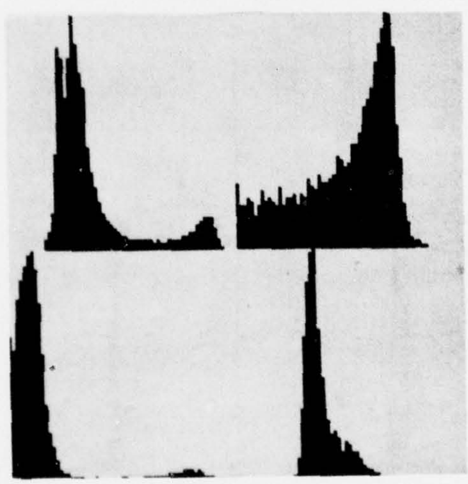


Figure 2. Gray level histograms for the pictures in Figure 1

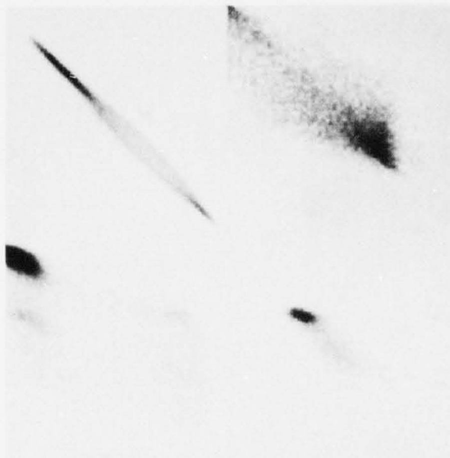


Figure 3. (Gray level, local average gray level) scatter plots for the pictures in Figure 1. Gray level increases downward; average gray level increases to the right.

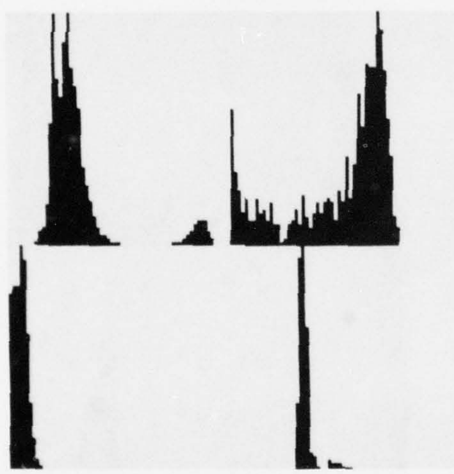
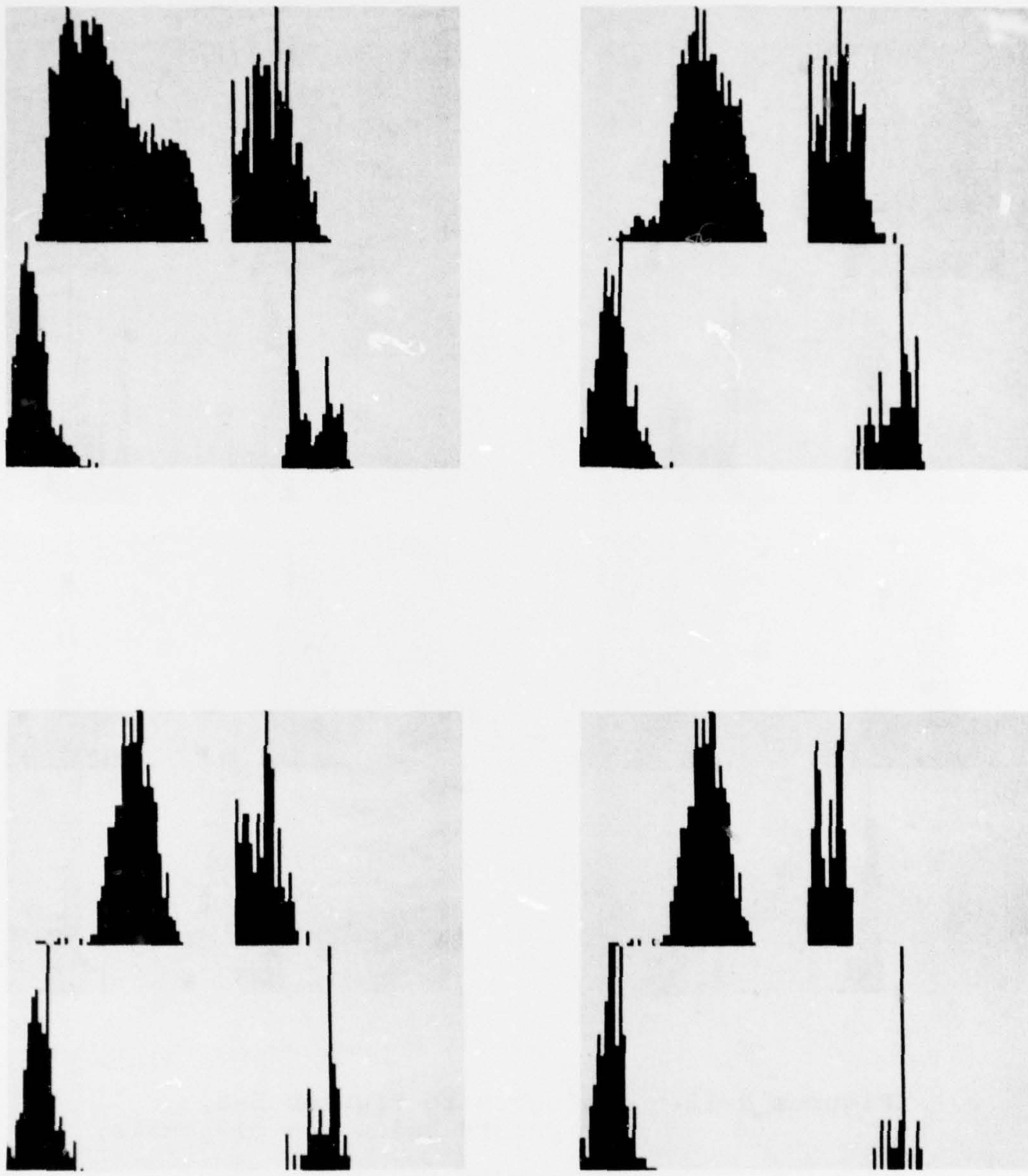
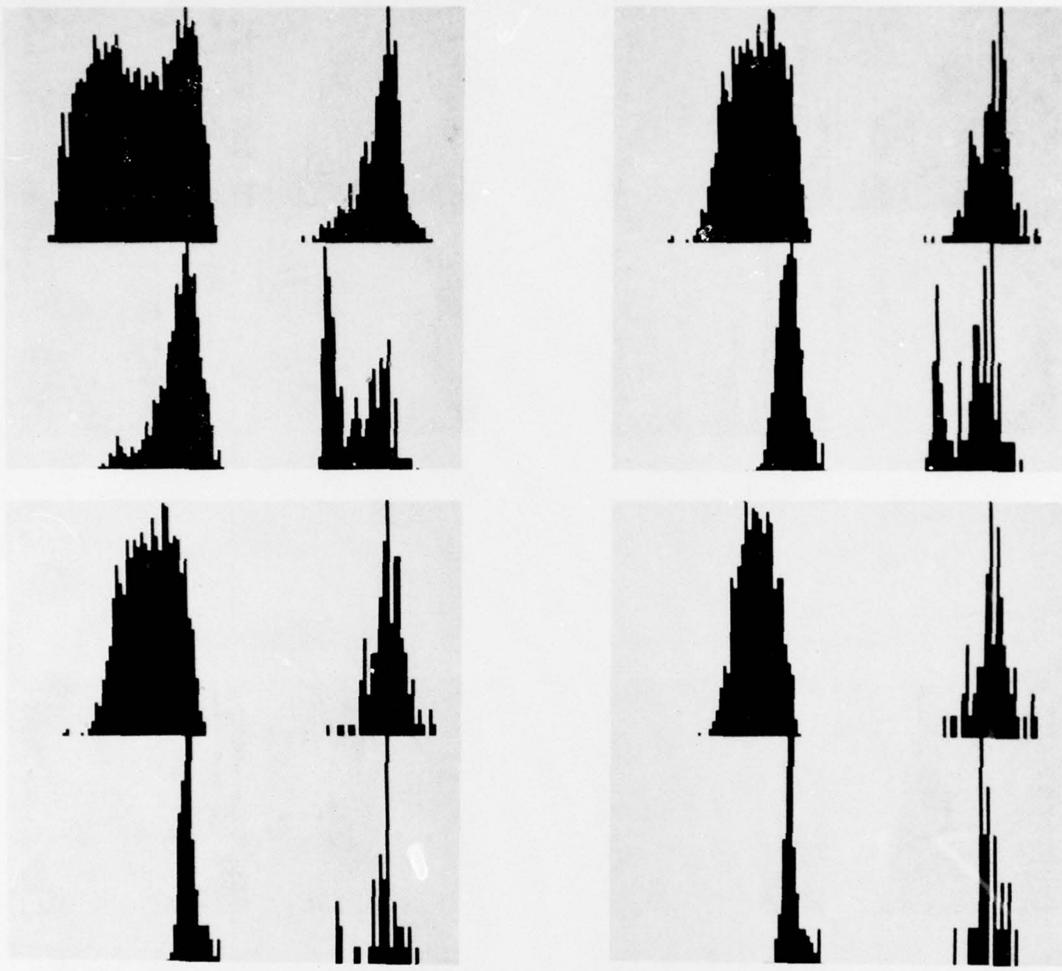


Figure 4. Gray level histograms of the points on the diagonals of the scatter plots.



Figures 5-8. Gray level histograms of the
5% 2%
1% 1/2% of the points farthest
above the diagonals of the scatter
plots.



Figures 9-12. Analogous to Figures 5-8, for points below the diagonals.

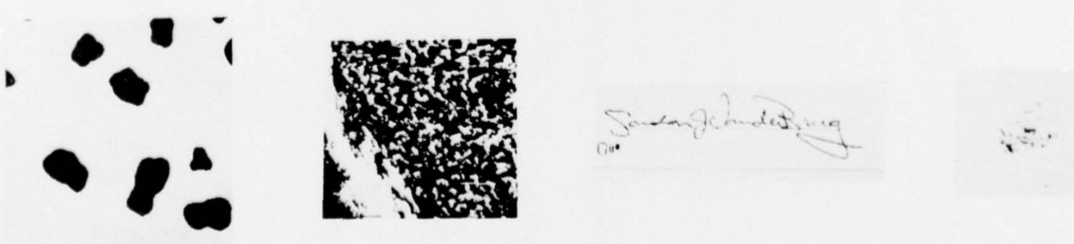


Figure 13. Results of thresholding the four pictures at 38, 24, 30, and 34, respectively.

Picture in Figure	Histogram in Figure	Mean	Mode	Picture in Figure	Histogram in Figure	Mean	Mode
1a	5	29	18	1c	5	9	6
	6	34	32		6	10	11
	7	34	36-37		7	9	11
	8	35	36-37		8	9	8-11
	9	36	50		9	47	50
	10	40	44		10	50	50
	11	40	44		11	51	50-51
	12	41	38		12	52	50-51
1b	5	10	12	1d	5	22	17
	6	8	8		6	24	26
	7	7	8		7	24	26
	8	6	9		8	25	26
	9	40	42		9	33	25
	10	41	44		10	36	42
	11	42	41-44		11	40	42
	12	43	42		12	42	40

Table 1. Means and modes of the histograms in Figures 5-12.

Picture in Figure	Histograms in Figures	Mean of Means	Mean of Modes	Picture in Figure	Histograms in Figures	Mean of Means	Mean of Modes
1a	5,9	32	34	1c	5,9	28	28
	6,10	37	38		6,10	30	30
	7,11	37	40		7,11	30	31
	8,12	38	37		8,12	30	30
1b	5,9	25	27	1d	5,9	28	21
	6,10	24	26		6,10	30	34
	7,11	24	25		7,11	32	34
	8,12	24	26		8,12	34	33

Table 2. Means of means and of modes for the four pictures.

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